

FATE OF TYPICAL LAKE PLANKTON IN STREAMS

A DISSERTATION SUBMITTED IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY IN
THE UNIVERSITY OF MICHIGAN

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Reprinted from
ECOLOGICAL MONOGRAPHS
Vol. 7, No. 4, 1937

ECOLOGICAL MONOGRAPHS

VOL. 7

OCTOBER, 1937

No. 4

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FATE OF TYPICAL LAKE PLANKTON IN STREAMS*

INTRODUCTION

The belief that a lake supports a plankton fundamentally different from that of flowing water was first expressed by Zacharias (1898) when he proposed the term *potamoplankton* to designate a definite group of plankton organisms which he believed to exist only in running water. In subsequent investigations on streams and lakes, it was claimed that there are characteristic differences between the plankton of the two situations and that these differences can be explained on the basis of contrasting environmental conditions. Knowledge concerning differences between the plankton of a stream and of a lake has been derived primarily from a comparison of results of independent investigations on each of these situations. Up to the present, it has not been demonstrated what happens to lake plankton when it is subjected to the environmental conditions of a stream. The purpose of this paper is to present the results of a study of streams without tributaries or pollution deriving water directly from a lake. In such a situation, plankton produced in a typical lake is suddenly subjected to the environmental conditions of a stream.

Work was begun in June, 1930, and continued to the spring of 1934. During this period three situations were studied. In the region of Ann Arbor, Michigan, there are two lakes, Base Line and Portage, the outlets of which unite to form a portion of the Huron River. These lakes and the succeeding five-mile portion of the river were studied continuously over a period of eighteen months, during which time two or three plankton collections were made each month. In the region of Douglas Lake, Michigan, two situations were studied, namely, Maple River, which has its source in Douglas Lake, and Bessey Creek, which has its source in Lancaster Lake. Both were investigated during the summers of 1930, 1932, and 1933. Also, in late October, 1932, and in November, 1933, work was done on Maple River. Lancaster and Douglas lakes were investigated only to the extent of determining the quality and quantity of plankton which they contributed to Bessey Creek and Maple River respectively.

During this investigation, 600 plankton samples were studied qualitatively and quantitatively. Approximately 400 were collected from Portage Lake, Base Line Lake and from that portion of the Huron River formed by the union of the outlets of these lakes. About 125 samples were taken from Maple River and 75 from Bessey Creek. In addition, numerous collections of aquatic vegetation, bottom ooze, sediment and various kinds of débris occurring in these streams were made and studied in relation to this problem. Certain physical-chemical analyses were made on each situation.

Base Line Lake (Fig. 1) is located about 18 miles northwest of Ann

* Contribution from the Department of Zoology and from the Biological Station, University of Michigan.

Arbor, Michigan. It, with Portage Lake, is at the lower end of a series of lakes lying in the upper portion of the Huron River drainage system. It is about 1 mile long and 0.7 mile wide. That part giving rise to the outlet is a narrowly constricted bay with steep sides and a maximum depth of 12 meters. The outlet is approximately 15 meters wide with an average depth of 1.5 meters.

Portage Lake (Fig. 1) located about 0.2 mile west of Base Line Lake is 2.5 miles long and about 1 mile wide. That portion of the lake used for work has a depth of 15 meters. The outlet, located at the southeastern extremity, unites with the outlet of Base Line Lake to form the beginning of the lower course of the Huron River. This has a width of about 8 meters and an average depth of approximately 1 meter.

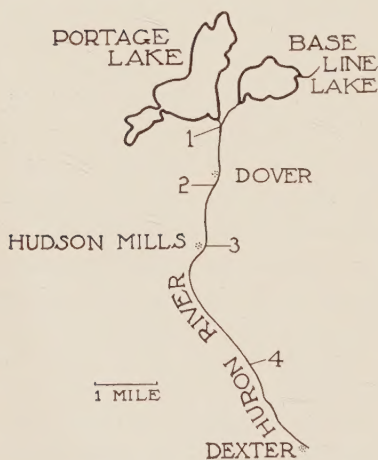


FIG. 1. Map showing Portage Lake, Base Line Lake and that portion of the Huron River between Dexter, Michigan, and union of the outlets of the two lakes. Collecting stations indicated by Arabic numerals.

Modified from the United States Geological Survey Map, Dexter Quadrangle, Michigan.



FIG. 2. Map showing Lancaster Lake, Bessey Creek and that portion of Douglas Lake into which Bessey Creek empties. Collecting stations indicated by Arabic numerals.

Modified from airplane map made by the United States Army, United States Geological Survey, and Department of Conservation, State of Michigan.

That part of the Huron River (Fig. 1) considered in this study was the portion lying between Dexter, Michigan, and the point of union of the outlets of Base Line and Portage Lakes. This section has a rather uniform course characterized by the lack of pronounced rapids or backwaters and the presence of a regular shore line. The river is free from pollution and

has no tributaries except for a few small temporary streams existing only during rainy seasons. Average current rate in this part of the river is approximately 0.4 mile per hour and does not vary greatly throughout the entire 5 miles. The water varies in width from 25 to 50 meters but the greater part of it is about 35 meters wide. Average depth is about 1.5 meters. Its substratum throughout the 5 miles is composed of mud, sand and gravel except on the riffles where stones predominate. The margins, and in many instances the entire river bed, support a copious growth of aquatic vegetation.

Bessey Creek (Fig. 2), the outlet of Lancaster Lake (Eggleton 1935), flows southward for a distance of 1.6 miles and empties into Douglas Lake. The width of the stream varies from 3 to 5 meters while the depth ranges from 15 to 18 centimeters on riffles to about 1.5 meters in pools. Rate of current is approximately 0.3 mile per hour throughout the entire course of the stream. This stream is free from pollution and has no tributaries.

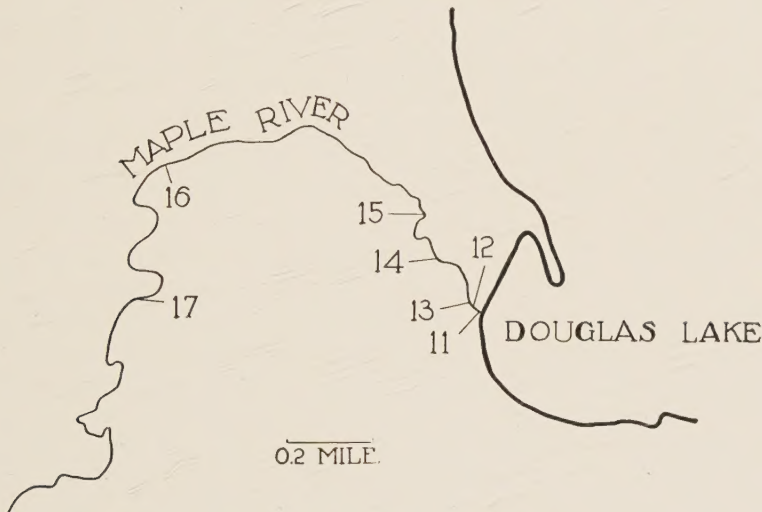


FIG. 3. Map showing a portion of Maple River and the region of the outlet of Douglas Lake. Collecting stations indicated by Arabic numerals.

Modified from airplane map made by the United States Army, United States Geological Survey, and Department of Conservation, State of Michigan.

Maple River (Fig. 3) is the outlet of Douglas Lake and empties into Burt Lake. That part considered in this work is the portion between Douglas Lake and the Bryant-Pellston road, having a length of about 1.6 miles. At the outlet of Douglas Lake, the stream is approximately 3 meters wide and about 25 centimeters deep. The entire investigated portion is free from pollution and does not have tributaries.

The writer wishes to express his indebtedness to Professor Paul S. Welch under whose direction work was done; to Professor W. R. Taylor for aid in identification of diatoms; and Professor J. H. Ehlers for assistance in

identification of certain higher aquatic plants. The assistance of many associates during this investigation is gratefully acknowledged.

METHODS AND EQUIPMENT

All temperature determinations in streams were made with a centigrade maximum-minimum thermometer, properly corrected. A Negretti and Zambra reversing thermometer was used in making temperature records in lakes.

Rate of current was measured by the float method. A bottle filled with water, until it nearly submerged, was allowed to drift a known distance. The time it took the float to travel this distance was determined with a stop watch and the rate was expressed in miles per hour. In some instances a floating cork was used.

Water samples for all chemical analyses were collected with a modified Kemmerer bottle. Hydrogen-ion concentration was determined by means of a colorimeter. Dissolved oxygen, free carbon dioxide and carbonates were determined by methods outlined in the Standard Methods for the Examination of Water and Sewage, 6th edition (1925).

All net plankton samples from streams were secured by pouring 100 liters of water through a No. 20 silk bolting cloth plankton net. In most instances, collecting stations were established at positions in the streams where water was shallow enough to wade from one shore to the other. Plankton samples from lakes consisted of 20 liters of water collected by means of a modified Kemmerer bottle. This water was also poured through a No. 20 silk bolting cloth plankton net. The concentrate from each sample was preserved immediately with formalin. Examination of plankton samples in the laboratory consisted of a qualitative and quantitative enumeration of plankters with a Sedgewick-Rafter cell and a Whipple micrometer. Concentrate of each sample was diluted to 100 cubic centimeters and mixed thoroughly until the organisms were uniformly distributed. Small and common organisms were counted in 5 cubic millimeters in each of 2 different cubic centimeters of the concentrate. The survey method was employed to enumerate the rarer and larger organisms, such as Crustacea, Rotifera and certain Protozoa, in 2 cubic centimeters of the concentrate.

STATIONS

HURON RIVER

Station 1 (Fig. 1) was located 50 meters below the point of union of the outlets of Portage and Base Line Lakes. Water at this station was approximately 40 meters wide, 1 meter deep, and the current was 0.4 mile per hour. The substratum consisted of sand, small stones and numerous clam shells coated with marl. Sparse aquatic vegetation consisted of the following species: *Chara* sp. *Elodea canadensis*, *Ceratophyllum demersum*, *Potamogeton*

pectinatus, *P. americanus*, *P. amplifolius*, *P. angustifolius*, *P. zosterifolius*, *P. Richardsonii*, and *Vallisneria spiralis*.

Plankton collections were made regularly at the outlets of Portage and Base Line Lakes in order to determine the quality and quantity of plankton each was contributing to the river. These collections were used also to show that plankton at Station 1 represented the combined plankton of the two outlets.

Station 2 was located just below the bridge at Dover, approximately 1 mile down stream from Station 1. Here, water was no more than 0.5 meter deep due to the width of the river, and the current rate was about 0.4 mile per hour. The substratum, consisting mostly of small stones and sand, supported a scant growth of aquatic vegetation.

Station 3 was established 1 mile down stream from Station 2, about 50 meters below the bridge at Hudson Mills, where the channel was about 1 meter deep and the current rate 0.8 mile per hour. This relatively swift section was only a few meters long and free from aquatic vegetation. However, above and below this station the river supported an abundance of vegetation.

Station 4 was 2.5 miles below Station 3. The water was uniformly deep, about 1.3 meters, and flowed at the rate of 0.3 mile per hour. Approximately 0.5 mile above and below this station, the substratum was composed of sand and muck which supported a dense growth of vegetation, especially during late summer.

BESSEY CREEK

Station 5 (Fig. 2) was near the outlet of Lancaster Lake where water had definitely left the lake and had become a part of the stream. Water was 3.5 meters wide and about 1 meter deep in mid-channel. The substratum consisted of an old bog mat on which a large amount of flocculent sediment and muck had accumulated. Aquatic vegetation produced a continuous bed from this station to the next one during late summer. At times of maximum vegetation the stream became nearly choked due to heavy growths of *Najas flexilis*, *Nymphaea advena*, several species of *Potamogeton* and a very profuse growth of *Lyngbya* which produced an almost continuous mat across the stream. Rate of current at this station and the succeeding one was 0.3 mile per hour.

Station 6 was 15 meters below Station 5 and at the lower edge of the vegetation bed extending between these two stations. The general features were nearly identical with those of the preceding station.

Station 7 was 0.1 mile down stream from Station 6. Here, water was very sluggish, having a width of 3 meters and a depth of 12 centimeters. The substratum consisted of sand covered with brown flocculent sediment and vegetation was absent except at the margin of the stream. Rate of current at this station and the three succeeding stations was approximately 0.2 mile per hour.

Station 8 was about 0.1 mile below Station 7 and 0.2 mile from Lancaster Lake. The water was 2.5 meters wide and no more than 13 centimeters deep. There was no vegetation for some distance above and below this station, but the stream contained large accumulations of fallen leaves and branches, especially during late summer. In several places, trees had fallen across the stream producing partial dams.

Station 9 was 0.4 mile below Station 8 and 0.6 mile from Lancaster Lake. Here, water was confined to a narrow channel with a width of 1.5 meters and a depth of approximately 13 centimeters. The channel contained several large stones covered with algae and débris. There were no higher aquatic plants at this station; however, there were heavy beds just above and below it.

Station 10 was 0.5 mile below Station 9. This section was sluggish due to the presence of numerous pools containing dense beds of vegetation. The substratum, as in other vegetated sections, was composed of muck and sand covered with a layer of flocculent sediment.

MAPLE RIVER

Station 11 (Fig. 3) was near the outlet of Douglas Lake where the water had definitely left the lake and had become a part of the stream. Here, water varied from a width of 3 meters and a depth of 20 centimeters, during early summer, to a width of 2 meters and a depth of 10 centimeters in late summer. Rate of current was about 0.4 mile per hour. The substratum was composed of flocculent marl particles washed in from the lake, forming a soft oozy bed 1 meter or more deep. This material was constantly being thrown into suspension by water currents but it settled rather quickly in the less turbulent marginal water. There was a heavy growth of vegetation, during the summer, from this station to Station 13. The predominant plants were: *Najas flexilis*, *Potamogeton heterophyllus*, *P. natans*, *Scirpus validus*, and *Chara* sp.

Stations 12 and 13 were in the same vegetation zone near the outlet of the lake, about 10 meters and 20 meters respectively, down stream from Station 11. These three stations possessed the same general characteristics.

Station 14 was 0.16 mile below Station 13. The water, which was about 3.5 meters wide and 25 centimeters deep, flowed over a uniform sand bottom free from vegetation except at the margins. Rate of current was 0.3 mile per hour. There was no vegetation above or below this station for several meters, but there were pronounced accumulations of dead leaves and débris during late summer.

Station 15 was 0.15 mile below Station 14 and approximately 0.3 mile from the lake. The water, about 5 meters wide and 20 centimeters deep, flowed at the rate of 0.4 mile per hour. A substratum of sand was free from vegetation all summer except at the margins. This section contained accumulations of leaves during late summer.

Station 16 was 0.8 mile below Station 15 and about 1.1 miles from the lake. Here, the water was 3 meters wide and 25 centimeters deep and flowing at the rate of 0.3 mile per hour. This section was partly clogged with leaves and débris but there was very little vegetation.

Station 17 was 0.5 mile below Station 16 and 1.6 miles from the lake. The width, depth and rate of current were about that of the preceding station. The sandy and stony substratum supported no vegetation.

PLANKTON DATA

HURON RIVER SITUATION

CONSTITUENT PLANKTON ORGANISMS

During this investigation, 115 species and 96 genera of plankters were identified. The complete list of plankters and a discussion of their seasonal variation will appear in another paper. Approximately 95 per cent of these plankters was the product of the lakes, the remaining 5 per cent was the product of the river. These were distributed among the plankton groups as follows :

<i>Phytoplankton</i>	<i>Genera</i>	<i>Species</i>
Myxophyceae	9	11
Bacillariales	23	31
Chlorophyceae	17	15
Total	49	57
<i>Zooplankton</i>		
Protozoa	15	17
Rotifera	24	32
Crustacea	8	9
Total	47	58
Grand Total	96	115

Table 1 shows the relative proportion of constituent plankton groups, at various stations, to the total net plankton. This table is based upon data collected over a period of eighteen consecutive months and expresses the average percentage composition of each constituent group in relation to total net plankton at each station.

The significance of these data lies in the fact that all stations show a close similarity to each other in their average percentage composition of the major plankton groups. This indicates that plankton, introduced at Station 1 by the outlets of the two lakes, maintained its proportion of constituent groups for the 5 miles of river under investigation. The proportion was especially well maintained between total phytoplankton and zooplankton. This demon-

TABLE 1. Average Percentage Composition of Plankton.

Organisms	STATIONS			
	1	2	3	4
Phytoplankton				
Myxophyceae.....	10.00	11.20	15.17	17.36
Bacillariales.....	75.00	70.00	71.00	71.00
Chlorophyceae.....	2.00	6.65	4.21	.94
Total.....	87.00	87.85	90.38	89.30
Zooplankton				
Protozoa.....	11.00	10.75	8.26	9.23
Rotifera.....	1.50	1.17	1.19	1.25
Crustacea.....	.50	.23	.17	.22
Total.....	13.00	12.15	9.62	10.70
GRAND TOTAL.....	100.00	100.00	100.00	100.00

strates rather clearly that there were no significant sources of plankton supply other than the lakes. In the case of Myxophyceae and Chlorophyceae a rather noticeable variation does exist between stations. This variation is explained by additions of these groups from growths occurring at the margins of the river. However, the increase in percentage of these groups over that at Station 1 is rather insignificant and does not disturb the original proportion to any great extent.

Qualitatively, the Myxophyceae show a very irregular production and constitute from 1 to 25 per cent of the total net plankton. Bacillariales were always found to be the dominant group, constituting from 30 to 90 per cent of the total net plankton. Chlorophyceae never exceeded 12 per cent and often were absent. Protozoa showed the greatest irregularity among the zooplankton and constituted from 1 to 20 per cent of the total net plankton. This irregularity was due to seasonal variations of *Ceratium* and *Dinobryon* in the lakes. Rotifera and Crustacea showed seasonal variations but neither composed more than 5 per cent of the total net plankton at any time. Thus, even though the individual groups did vary within certain limits, the ratio between zooplankton and phytoplankton remained almost constant.

COMPARISON OF STATIONS

Table 2 represents data from plankton collections taken at each station on the river. These data demonstrate that at all times the lake plankton entering the river decreased as it progressed down stream. This phenomenon was demonstrated for total net plankton (Fig. 4) and for each of the following plankton groups: diatoms (Fig. 5), Rotifera (Fig. 6), and Crustacea (Fig. 7).

This quantitative decrease of lake plankton as it passed down stream was not limited to any one section of the river, but involved the entire 5

miles investigated. The factors responsible for the plankton decrease were effective shortly after plankton entered the river and continued as long as any plankton remained. It is a significant fact that plankton at any particular station always showed a greater quantity than at any station below it and a smaller quantity than at any station above it. However, the percentage of decrease between stations showed a variation at different times of the year but there was always a decrease of total net plankton of not less than 40 per cent between Stations 1 and 4. Station 2 showed a very consistent decrease which is of considerable significance since the distance involved was only 1 mile. On several occasions this decrease approached 50 per cent and on August 12, 1932 (Table 2), it was 83 per cent. However, the average decrease between Stations 1 and 2 for the 18 months was approximately 25 per cent.

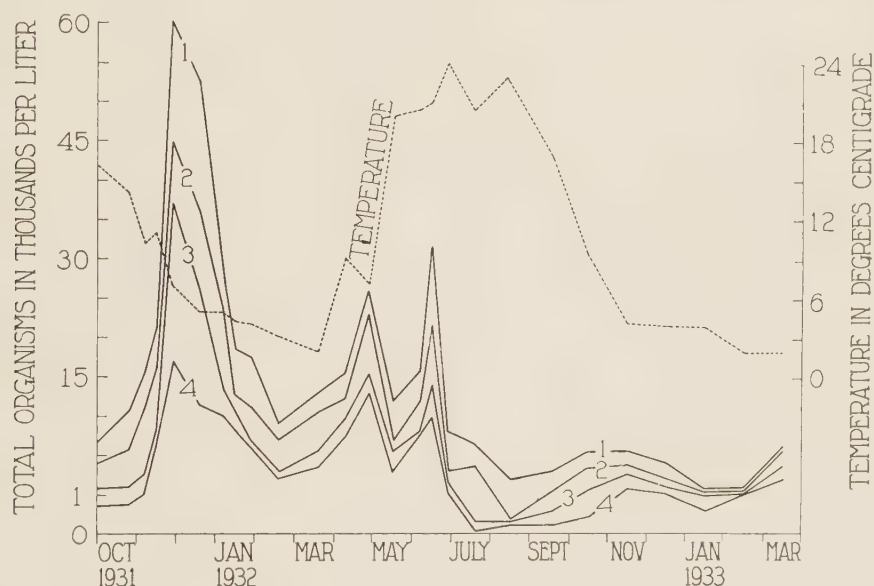


FIG. 4. Graphs showing total net plankton, in thousands per liter, at each station on the Huron River, from October, 1931, to March, 1933. Also a graph showing the temperature in degrees centigrade at Station 1 during the same period. Collecting stations indicated by Arabic numerals.

It is believed that the quantitative decrease of lake plankton entering the river is related to the following factors: amount of aquatic vegetation, water level, and volume of lake plankton entering the river. In July, 1932 (Table 2), there occurred a decrease of 99 per cent between Stations 1 and 4 while in February, 1933, there was a decrease of 41 per cent. Thus, at certain times of the year, lake plankton entering the Huron River disappeared almost completely by the time it had flowed the distance of 5 miles, while at other times, plankton decreased only 40 per cent over the same distance. This wide variation probably has its explanation in certain environmental factors which likewise exhibit a definite fluctuation during the year.

The influence that the above factors have on the decrease of lake plankton entering the river may be indicated by correlating the intensity of these factors with the per cent of plankton decrease at various times of the year. From October 21 to November 11, 1931 (Table 2), lake plankton entering the river underwent an average decrease of 91 per cent as it flowed from Station 1 to 4. During this time aquatic vegetation was abundant, water level was relatively low, and the average quantity of plankton organisms entering the river was 10,500 per liter. From November 18 to December 2, 1931, lake plankton entering the river underwent an average decrease of 77 per cent as it flowed from Station 1 to 4. At this time aquatic vegetation in the river was less abundant than during the preceding period, water level



FIG. 5. Graphs showing total net diatoms, in thousands per liter, at each station on the Huron River, from October, 1931, to March, 1933. Collecting stations indicated by Arabic numerals.

was relatively high, and the average quantity of plankton organisms entering the river was 44,600 per liter. From January 6 to March 14, 1932, plankton entering the river underwent an average decrease of 66 per cent as it flowed from Station 1 to 4. In comparison to the preceding period, aquatic vegetation was scarce, water level was lower, and the average quantity of plankton organisms entering the river was 17,000 per liter. From April 20 to June 9, 1932, the average quantity of plankton organisms entering the river was 20,000 per liter, and the average decrease of this plankton as it flowed from Station 1 to 4 was 58 per cent. Aquatic vegetation in the river was scarce, and the water level was higher than the preceding period. From June 22 to October 18, 1932, the average quantity of lake plankton entering the



FIG. 6. Graphs showing the quantity of plankton rotifers per liter, at each station on the Huron River, from October, 1931, to March, 1933. Collecting stations indicated by Arabic numerals.

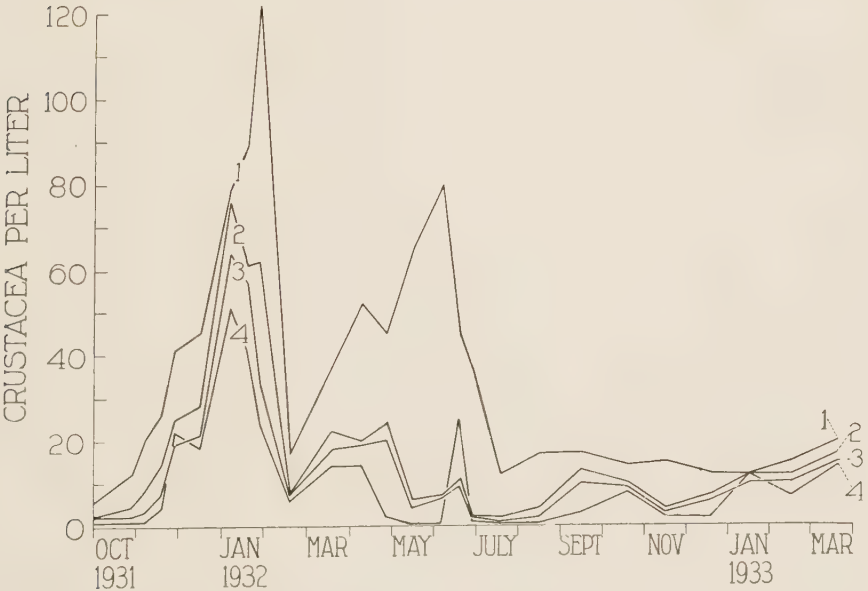


FIG. 7. Graphs showing the quantity of plankton Crustacea per liter, at each station on the Huron River, from October, 1931, to March, 1933. Collecting stations indicated by Arabic numerals.

river was 5,000 organisms per liter, and this plankton underwent an average decrease of 92 per cent as it flowed from Station 1 to 4. Aquatic vegetation in the river was abundant, and water level was lower than the preceding period. From November 30 to December 10, 1932, the average quantity of plankton organisms entering the river was 4,800 per liter, and this plankton underwent an average decrease of 73 per cent as it flowed from Station 1 to 4. Aquatic vegetation in the river was less than the preceding period, and water level was higher. From January 25 to March 20, 1933, the average quantity of plankton organisms entering the river was 3,000 per liter, and the average decrease of this plankton was 54 per cent as it flowed from Station 1 to 4. Aquatic vegetation in the river was scarce, and water level was lower than the preceding period.

It is evident from the above data that lake plankton flowing from Station 1 to 4 underwent the greatest decrease during times when aquatic vegetation was most abundant and water level the lowest. Also, the smallest decrease of this plankton, flowing from Station 1 to 4, was at times when aquatic vegetation in the river was scarce and water level was high. The intermediate degrees of decrease occurring between these extremes can be correlated with variation of environmental factors. It is believed that the importance of quantity of plankton entering the river lies in the fact that the greater the number of organisms per liter of water the greater the chance

TABLE 2. Total plankton organisms per liter in the Huron River, 1931, 1932, 1933.

Date		STATIONS			
		1	2	3	4
October	21.....	6,555	4,087	1,602	701
October	28.....	10,712	5,619	1,802	751
November	11.....	20,470	11,208	2,303	996
November	18.....	21,385	14,384	8,846	5,819
November	26.....	59,991	45,165	37,325	16,896
December	2.....	52,599	35,963	26,125	11,496
January	6.....	27,539	23,620	13,289	9,919
January	13.....	19,646	12,683	10,462	8,026
January	27.....	17,593	11,255	6,917	6,181
February	27.....	9,002	7,046	2,936	2,334
March	14.....	12,588	10,537	5,513	3,559
April	20.....	15,249	12,370	9,763	7,530
April	27.....	26,468	23,642	15,205	13,246
May	25.....	12,043	7,037	5,465	3,877
June	1.....	15,818	12,192	8,237	7,895
June	9.....	31,805	21,544	13,972	10,169
June	22.....	7,914	3,074	2,122	1,208
July	8.....	6,502	3,623	349	12
August	12.....	1,921	323	308	203
September	29.....	3,152	1,053	620	207
October	18.....	5,559	3,470	1,024	413
November	30.....	5,576	3,810	2,610	1,607
December	10.....	4,027	2,017	1,513	1,005
January	25.....	1,571	1,424	1,318	618
February	28.....	1,883	1,625	1,325	1,120
March	20.....	6,075	5,555	3,360	2,049

that they will be removed from the water as they flow down stream. This particular point is discussed in a later section of this paper dealing with Bessey Creek and Maple River.

BESSEY CREEK-LANCASTER LAKE SITUATION

CONSTITUENT PLANKTON ORGANISMS

During this study, 84 species and 91 genera of plankters were identified. The complete list of plankters and a general discussion of them will appear in another paper. These were distributed among the plankton groups as follows:

<i>Phytoplankton</i>	<i>Genera</i>	<i>Species</i>
Myxophyceae	10	11
Bacillariales	21	21
Chlorophyceae	16	12
	—	—
Total	47	44
<i>Zooplankton</i>		
Protozoa	11	8
Rotifera	25	26
Crustacea	8	6
	—	—
Total	44	40
Grand Total	91	84

The composition of plankton entering Bessey Creek from Lancaster Lake varied greatly during different summers and at different times of the same summer. Since this study was limited to summer months when a minimum quantity of plankton was present, it is impossible to determine anything significant by computing the average percentage composition as was done for the Huron River.

During August, 1932, zooplankton constituted quantitatively more than 50 per cent of the total net plankton of Bessey Creek; however, phytoplankton was present in significant amounts. Protozoa was the largest group and constituted approximately 50 per cent of the total net plankton. The predominant protozoans present at this time were *Ceratium* and *Dinobryon*. Rotifera and Crustacea appeared in quantities much greater in proportion to phytoplankton than was shown for the Huron River. Collections taken from Lancaster Lake during the summer of 1932, showed that the qualitative plankton composition of lake and stream was nearly identical.

Collections during early July, 1933, showed a predominance of phytoplankton over zooplankton in the stream. However, the latter was present in significant quantities. By July 17, 1933, net phytoplankton had completely disappeared so far as significant numbers were concerned. At this time, only an occasional algal form was encountered while making the routine quanti-

tative counts. Scarcity of phytoplankton continued until late August, 1933, when an increase of diatoms occurred. Collections in Lancaster Lake confirmed this scarcity of algal forms for the greater part of the summer of 1933. Collections in November, 1933, showed a large quantity of phytoplankton, especially the diatoms, and collections in early July, 1933, showed the presence of phytoplankton indicating that only during summer months does zooplankton predominate. Thus, a study of this situation makes it possible to determine if lake plankton predominated by zooplankton undergoes a quantitative decrease as it flows down stream.

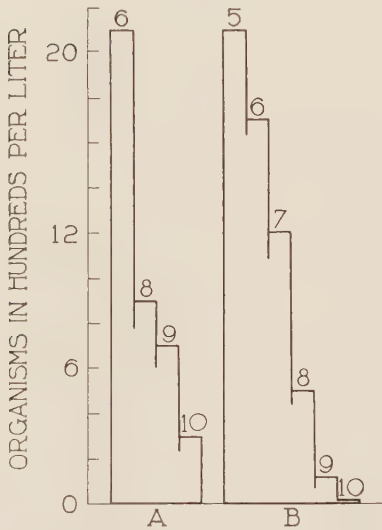


FIG. 8. A—Graph showing total net plankton, in hundreds per liter, at four stations on Bessey Creek, August 25, 1932. Collecting stations indicated by Arabic numerals.

B—Graph showing total net plankton, in hundreds per liter, at six stations on Bessey Creek, July 12, 1933. Collecting stations indicated by Arabic numerals.

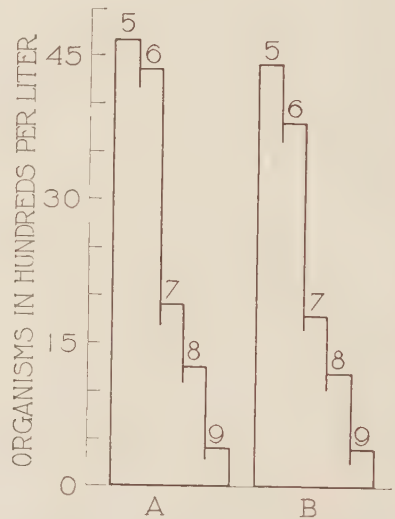


FIG. 9. Graphs showing quantity of plankton, in hundreds per liter, at five stations on Bessey Creek, November 4, 1933. A—Total net plankton; B—Total net plankton diatoms. Collecting stations indicated by Arabic numerals.

COMPARISON OF STATIONS

Entire Investigated Portion

The qualitative composition of total net plankton collected at each station on Bessey Creek was very similar to plankton leaving Lancaster Lake. When the qualitative plankton composition at a station differed from that of the outlet it was due to elimination of certain plankters from more distant stations or to addition of detached epiphytic forms. The quantity of plankton added by the stream itself was very insignificant and was not considered in this study.

Table 4 represents data from plankton collections taken at each station on Bessey Creek. These data show that lake plankton entering the stream always decreased in quantity as it flowed down stream. This phenomenon was demonstrated for the total net plankton (Fig. 8) and for each of the following plankton groups: diatoms (Fig. 9, B), Rotifera (Fig. 10, C), and Crustacea (Fig. 10, E).

This quantitative decrease of lake plankton as it flowed down stream was not confined to any special section of the stream but occurred throughout the entire investigated portion. Usually, the decrease of plankton was not uniform between stations, but at no time was the quantity at a station less than the quantity at a station below it or greater than at a station above it.

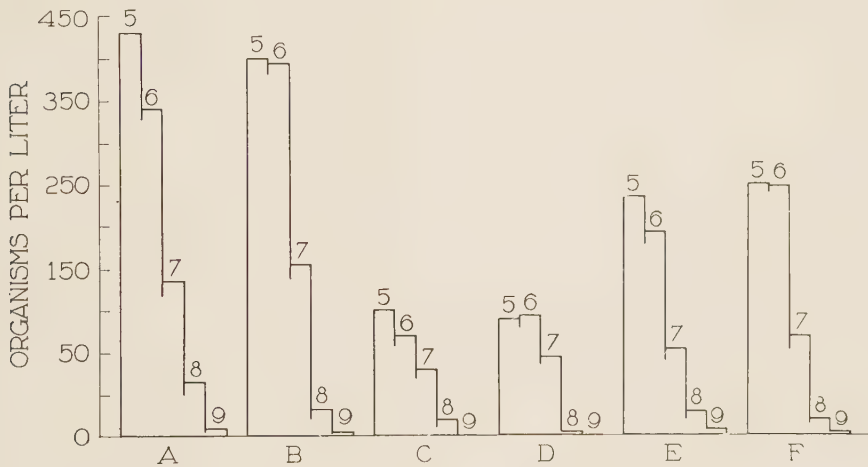


FIG. 10. Graphs showing quantity of plankton, per liter, at five stations on Bessey Creek, before and after vegetation removal, August 11, 1933, and August 14, 1933, respectively, between Stations 5 and 6. A—Total net plankton before vegetation removal; B—Total net plankton after vegetation removal; C—Total plankton rotifers before vegetation removal; D—Total plankton rotifers after vegetation removal; E—Total plankton Crustacea before vegetation removal; F—Total plankton Crustacea after vegetation removal. Collecting stations indicated by Arabic numerals.

The greatest decrease per unit of distance occurred within a short distance from the lake in a section of the stream that supported an abundance of vegetation. On August 25, 1932, a plankton collection (Fig. 8, A), which is representative of this particular summer, showed a decrease of 58 per cent between Stations 6 and 8, a distance of 0.2 mile. At Station 10 the quantity of plankton was only 14 per cent of that at Station 6. The collection of July 12, 1933 (Fig. 8, B), representative of this particular summer, likewise showed a pronounced decrease of lake plankton within a distance of 0.2 mile from the lake and nearly an absence of plankton at Station 10.

The quantitative decrease, effective for total net plankton entering the stream, was likewise effective for each individual plankton group. However, the Myxophyceae and Chlorophyceae, in several instances, showed an

increase in quantity due to additions from the margins of the stream. These additions were irregular and constituted a very small percentage of the total net plankton. The diatoms, composing approximately 50 per cent of the phytoplankton, always showed a decrease as they flowed down stream. At times when diatoms constitute a large percentage of the total net plankton they may be very important in producing the general features of a quantitative decrease between the lake and stations down stream (Fig. 9). Rotifera and Crustacea showed a decrease between stations nearly as consistently as did the diatoms. However, these two groups never occurred in large quantities but during summer they composed nearly the entire total net plankton. The quantity of these groups was always much greater at the outlet of Lancaster Lake than at any station on the stream. Almost invariably the most pronounced decrease of these groups occurred within 0.5 mile from the lake and often within a distance of a few meters.

Vegetation Zone

The fact that the greatest decrease of lake plankton entering the stream occurred in late summer in sections containing much vegetation suggested that vegetation was partly responsible for the decrease. In order to determine how vegetation might function in removal of plankton from the stream, a special study was made of the vegetated portion between Stations 5 and 6. In this study, numerous plankton collections were taken while vegetation existed under normal conditions. Later, vegetation was removed and more collections were taken.

Before Vegetation Removal

A quantitative plankton decrease occurred between Stations 5 and 6 (Table 4) throughout the summer of 1933. This decrease is of considerable significance when it is realized that the distance involved was only 15 meters. A conspicuous feature of this portion of Bessey Creek was the abundance of aquatic vegetation existing throughout the summer but increasing in abundance from early July to a maximum in late August. The vegetation consisted of a heavy mat of *Lyngbya* and the following macrophytes:

Potamogeton Richardsonii
Potamogeton natans
Potamogeton zosterifolius
Potamogeton Friesii
Najas flexilis
Utricularia vulgaris

Equisetum fluviatile
Myriophyllum sp.
Hippuris vulgaris
Nymphaea advena
Scirpus validis

A bed of aquatic vegetation of similar composition, except for *Lyngbya*, existed in Lancaster Lake near the outlet. However, there was a short distance between the vegetation bed of stream and lake containing little or no vegeta-

tion. *Lyngbya* at Station 5 formed what appeared to be a floating mat but actually it extended from surface to bottom of the stream and was held in position by intermingled growths of the macrophytes mentioned above. By August, 1933, this mat was so extensive that it nearly extended across the stream at Station 5 and down stream for a distance of about 8 meters. The remaining portion of the stream between Stations 5 and 6 was heavily vegetated but it lacked *Lyngbya*. Vegetation was so abundant in this zone that water leaving Lancaster Lake had to flow through some portion of the bed on its course down stream. Thus vegetation, especially that portion containing *Lyngbya*, acted more or less as a strainer for water leaving the lake. Throughout the summer of 1933 plankton leaving the lake underwent a quantitative decrease of 20 to 58 per cent as it flowed through this vegetation bed. The decrease was not due to the removal of any one plankton group or individual plankter but rather to the removal of some of each plankton component involved.

In order to determine how this vegetation was functioning in removal of plankton small quantities of vegetation, occurring between Stations 5 and 6, were collected and examined for adhering plankters. Examination of a small portion of the *Lyngbya* mat revealed the presence of many organisms normally occurring in plankton at Station 5, in addition to numerous non-plankters. The filaments were closely intermingled and matted, producing the characteristics of a very effective strainer. Large numbers of diatoms, the predominant species in the plankton, were identified in this mat especially at the time when they were most abundant in the lake. Large numbers of rotifers and Crustacea, the same species occurring in the plankton, were likewise observed in this mass of vegetation. In most instances these plankters were alive but often the remains of diatoms and hard parts of rotifers and Crustacea were observed. When algal forms dominated the plankton of Lancaster Lake, July 5-10, 1933, they appeared in greater numbers in the vegetation mat than did zooplankters. Later in the summer of 1933, when zooplankters were dominant, they appeared in greater numbers in the vegetation mat than did phytoplankters. Thus, it seemed that the *Lyngbya* mat was actually straining out plankton organisms leaving the lake. It was also observed that during the summer an accumulation of material formed around the stems of macrophytes. Rate of accumulation of this material increased throughout the summer. Examination showed this material to consist of particles of sediment, portions of decaying macrophytes, gelatinous stalks of ephytic diatoms, filamentous algae, numerous invertebrates not normally occurring in the plankton, and the predominant plankters represented in plankton at Station 5. This study involved no attempt to make a quantitative comparison between plankters found adhering to vegetation and those occurring in the plankton at Station 5. However, nearly every predominant plankter leaving the lake was represented in the *Lyngbya* mat or in the accumulations around stems of macrophytes.

After Vegetation Removal

On August 11, 1933, a plankton collection was taken at each station on Bessey Creek before any vegetation was removed. Immediately after this collection approximately all vegetation between Stations 5 and 6 was removed by means of a rake. On August 14, 1933, three days after vegetation removal, another collection was made at each station on the stream. Results of these two collections are compared in Figure 10 and in Table 3. To con-

TABLE 3. Organisms per liter in Bessey Creek before and after vegetation removal between Stations 5 and 6. Vegetation was not removed between Stations 6 and 7, 7 and 8, 8 and 9. Compare plankton numbers horizontally.

Vegetation	STATIONS				
	5	6	7	8	9
Before Removal.....	431	340	134	28	3
After Removal.....	401	398	151	16	2

firm these results a collection was made on November 4, 1933 (Table 4). This collection showed that lake plankton underwent a decrease as it flowed down stream but it was the least pronounced between Stations 5 and 6, as was true for August 14, 1933.

It is not possible, from this study, to state exactly how aquatic vegetation functions in removal of plankton from flowing water but it seems reasonable from the data herein presented that vegetation acts as a strainer. It is possible that organisms removed by this method accumulate in the meshes of the closely intermingled masses of vegetation or on stems of individual plants. It is also possible that some of these organisms remain alive for some time after their removal, others are doubtless eaten by non-plankton inhabitants

TABLE 4. Total plankton organisms per liter in Bessey Creek, 1932, 1933.

Date		STATIONS					
		5	6	7	8	9	10
August	22.....	.....	4,159	.....	1,313	704	...
August	23.....	.....	4,064	.....	1,031	708	...
August	25.....	.....	2,174	.....	914	704	302
August	26.....	.....	2,712	.....	615	510	...
July	5.....	.....	3,251	2,025	.....	...	...
July	10.....	.....	2,117	1,149	.....	...	...
July	12.....	2,092	1,732	1,196	484	103	3
July	17.....	508	244	217	.....	...	...
July	21.....	661	441	.....	16	...	...
July	26.....	.....	168	100	15	4	...
July	31.....	383	221	.....	.....	...	...
August	9.....	259	119	.....	.....	...	...
August	11.....	431	340	134	32	3	...
August	14.....	401	398	151	16	2	...
August	18.....	1,845	1,942	.....	.....	...	...
November	4.....	4,651	4,347	1,902	1,258	431	...

of the vegetation mass, and others die, adding to the accumulation of sediment. The greater the accumulation of material the more effective is the straining action. It appears that as material increases around the stems of plants it is often torn loose in masses which settle to the bottom or float down stream until they attach to some object. Examination of sediment accumulated beneath vegetation beds showed that its composition was nearly identical with material adhering to plants, which confirms the belief that the accumulated materials settle to the bottom.

MAPLE RIVER-DOUGLAS LAKE SITUATION

CONSTITUENT PLANKTON ORGANISMS

During the investigation of Maple River, 108 plankters were identified. There were 102 genera but in several instances no species identification was attempted. This plankton list will appear in a separate paper. Plankters were distributed among the plankton groups as follows:

<i>Phytoplankton</i>	<i>Genera</i>	<i>Species</i>
Myxophyceae	16	17
Bacillariales	22	24
Chlorophyceae	17	16
Total	55	57
<i>Zooplankton</i>		
Protozoa	14	12
Rotifera	23	28
Crustacea	10	11
Total	47	51
Grand Total	102	108

Plankton entering Maple River from Douglas Lake showed a distinct predominance of phytoplankton over zooplankton, throughout the period of investigation. Bacillariales always occurred in larger numbers than any other plankton group and constituted on the average about 75 per cent of the total net plankton. At the outlet of Douglas Lake, the minimum number of diatoms at any one time was 1,000 per liter while the maximum was 40,900 per liter. Myxophyceae were always present at the outlet in numbers not less than 1,000 per liter and not more than 2,500 per liter. This group constituted not more than 10 per cent of the total net plankton. Chlorophyceae were always present but often in small numbers and constituted a small percentage of the total net plankton. Zooplankton seldom constituted more than 10 per cent of the total net plankton and often much less. The three zooplankton groups were consistently represented in each collection but always in smaller numbers than the phytoplankton groups. In general, the plankton composition of Maple River resembles that of the Huron River more closely than it does that of Bessey Creek.

COMPARISON OF STATIONS

Entire Investigated Portion

Total net plankton collected at each station on Maple River had a qualitative composition similar to the plankton leaving Douglas Lake. If there were a difference it was due to elimination of certain plankters from the more distant stations or to the addition of detached epiphytic forms. The number of organisms added by the stream was insignificant thus they received no consideration in this study.

Table 6 represents data from plankton collections taken at various stations on Maple River. These data show that plankton entering Maple River from Douglas Lake decreased quantitatively as it flowed down stream. The

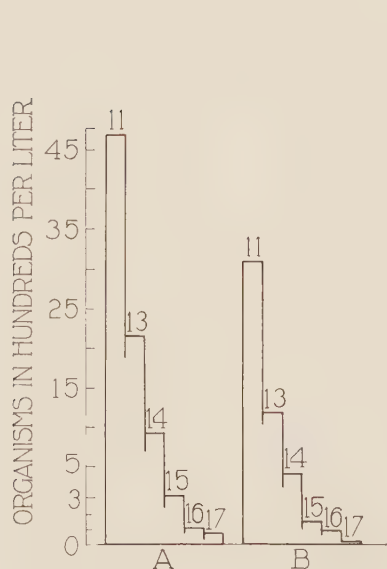


FIG. 11. Graphs showing quantity of plankton, in hundreds per liter, at six stations on Maple River, August 27, 1932. A—Total net plankton; B—Total net plankton diatoms. Collecting stations indicated by Arabic numerals.



FIG. 12. Graphs showing quantity of plankton, in thousands per liter, at five stations on Maple River, October 28, 1932. A—Total net plankton; B—Total net plankton diatoms. Collecting stations indicated by Arabic numerals.

general features of this decrease are nearly identical with those exhibited by Bessey Creek and Huron River. Usually the greatest decrease per unit of distance took place a short distance from the lake in a heavily vegetated part of the stream. However, this decrease was not limited to any one section of the stream but involved the entire portion investigated. This phenomenon was demonstrated for total net plankton (Fig. 12, A) and for each of the following plankton groups: diatoms (Fig. 12, B), Crustacea (Fig. 13, A), and Rotifera (Fig. 13, B). When Chlorophyceae and Myxophyceae were present in significant numbers they likewise exhibited this quantitative decrease.

Vegetation Zone

A special study was made on the section of Maple River between Stations 11 and 13 for the purpose of determining if vegetation was an important factor in explaining the decrease of lake plankton after entering the stream. This section of the stream was characterized by an abundance of vegetation confined to definite beds. During early summer, vegetation occurred in small quantities and the stream showed a high water level. In late summer, vegetation reached a maximum production and the water level was very low. Thus, in this section of the stream the proportion of vegeta-

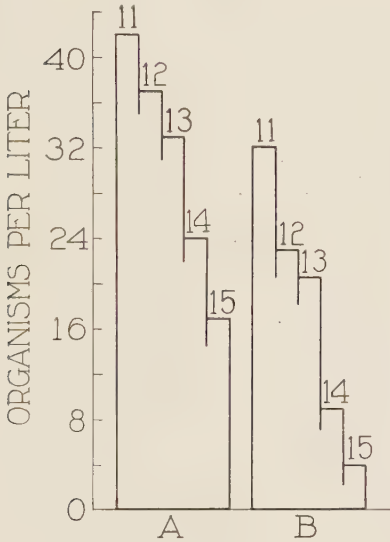


FIG. 13. Graphs showing quantity of plankton, per liter, at five stations on Maple River, October 28, 1932. A—Total plankton Crustacea; B—Total plankton rotifers. Collecting stations indicated by Arabic numerals.

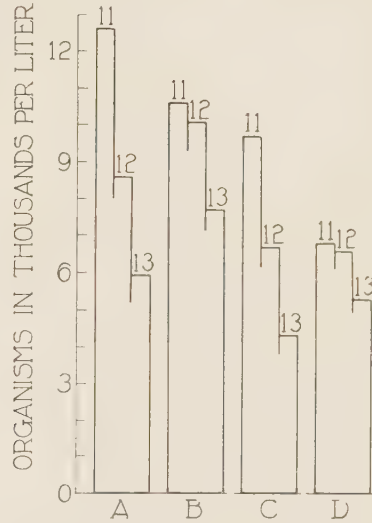


FIG. 14. Graphs showing quantity of plankton, in thousands per liter, at three stations on Maple River, August 28, 1933, before and after vegetation removal between Stations 11 and 12. A—Total net plankton before vegetation removal; B—Total net plankton after vegetation removal; C—Total net plankton diatoms before vegetation removal; D—Total net plankton diatoms after vegetation removal. Collecting stations indicated by Arabic numerals.

tion to volume of water increased from early to late summer, a factor believed to be of considerable significance in relation to this problem. Aquatic plants composing the greater percentage of the vegetation were:

Chara sp.
Najas flexilis
Potamogeton natans

Potamogeton heterophyllus
Elodea canadensis
Scirpus validis

Before Vegetation Removal

Each collection (Table 6) showed that plankton leaving the lake underwent a significant quantitative decrease as it flowed from Station 11 to 13.

The collection of August 27, 1932 (Fig. 11), showed a decrease of approximately 54 per cent between these stations, involving a distance of 20 meters. At this time, the volume of water leaving the lake was small and was confined to a heavily vegetated channel, between Stations 11 and 13, not more than 2 meters wide. On October 27, 1932, the plankton underwent a 70 per cent decrease as it flowed from Station 11 to 13. This collection was taken during the autumn overturn of Douglas Lake, thus a larger quantity of plankton was entering the stream. However, the water level and abundance of vegetation in the stream was about the same as during the August collection. The following summer, 1933, when this study was resumed the water level was high and vegetation was present in small quantities. Thus the proportion of vegetation to volume of water was very much smaller than during the October collection of 1932. Collections from June to early August of this summer showed that plankton flowing from Station 11 to 13 underwent a decrease of not more than 20 per cent. But in late August when the water level was again low and vegetation abundant there occurred a decrease of 50 per cent or more between these two stations.

Results obtained from this study of vegetation between Stations 11 and 13 revealed many conditions which were similar to those found in vegetation beds of Bessey Creek. Small quantities of vegetation were examined microscopically for adhering organisms and it was observed that the predominant organisms of the plankton were present in large numbers, in addition to numerous non-plankters. Plankters were found in the accumulations around stems of individual plants. The general nature of this material was similar to that described for Bessey Creek. Likewise, sediment beneath the vegetation, on examination, revealed large numbers of living and dead plankters associated with masses of amorphous material. It was evident that many plankters were removed from water as it flowed through the vegetation bed and these became associated with accumulations on stems of plants or settled to the bottom along with sediment and various kinds of débris.

Study of this vegetation between Stations 11 and 13 from early to late summer made it possible to secure certain information concerning formation of material around stems of plants and its relation to the decrease of lake plankton as it flowed through this portion of the stream. In late June, the small amount of vegetation occurring in this zone contained little or no adhering material and at this time there occurred a small decrease of plankton as it flowed from Station 11 to 13. Later in the summer accumulations on the stems of plants became very pronounced and likewise a large quantitative plankton decrease occurred in this zone. Careful examination of plant stems in early summer showed a complete absence of adhering material in some instances and in others stems showed the presence of certain filamentous algae, epiphytic diatoms with branched gelatinous stalks and masses of what appeared to be in part bacteria. Certain of these plants were marked, making it possible to examine the same plant periodically through-

out the summer. It was found that as the accumulations increased various kinds of non-plankters such as, insect larvae, turbellarians, stalked protozoans and various epiphytic algae, became more abundant. In general, this type of material which formed on submerged stems and leaves of plants was partly responsible for the removal of organisms from the plankton. It seemed that the greater the accumulation the more effective it became as a strainer. In late summer, accumulations were so great that portions of them became detached and either floated down stream or sank to the bottom. On several

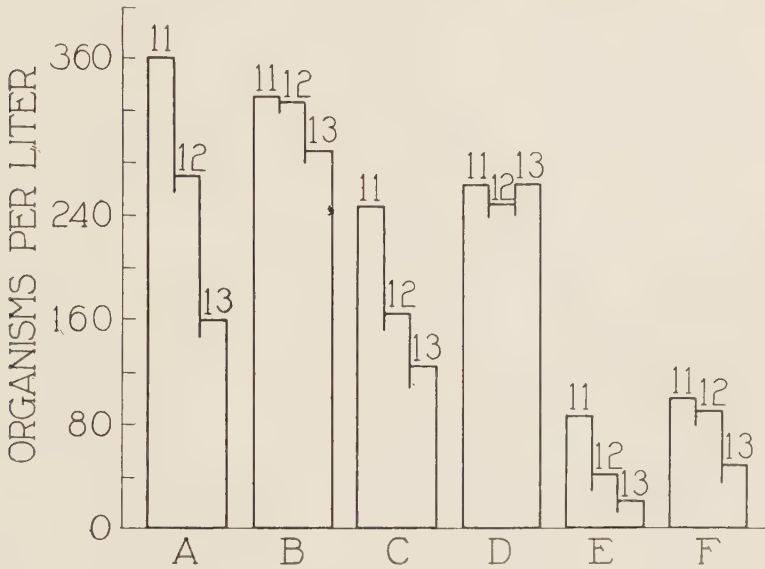


FIG. 15. Graphs showing quantity of plankton, per liter, at three stations on Maple River, August 28, 1933, before and after vegetation removal between Stations 11 and 12. A—Total plankton Protozoa before vegetation removal; B—Total plankton Protozoa after vegetation removal; C—Total plankton Crustacea before vegetation removal; D—Total plankton Crustacea after vegetation removal; E—Total plankton rotifers before vegetation removal; F—Total plankton rotifers after vegetation removal. Collecting stations indicated by Arabic numerals.

occasions, this vegetation zone was disturbed by walking through it resulting in the detachment of adhering material and sediment being thrown into suspension. Immediately following this disturbance, a collection taken at Station 13 invariably showed a quantity of plankton many times greater than one taken under normal conditions.

After Vegetation Removal

Data thus far presented indicate that vegetation is definitely related to the quantitative decrease of lake plankton as it flows down stream. It was realized that vegetation is not the only factor responsible for this decrease but, if it is as important as indicated, its removal would produce very evident results. Therefore, vegetation was actually removed between Stations

11 and 12 during its maximum growth in August, 1933, and the plankton study continued.

On August 28, 1933, a plankton collection was taken at Stations 11, 12, and 13 at 10:00 A.M. before any vegetation was removed. Immediately after this collection, vegetation was raked from the stream between Stations 11 and 12 until practically all plants were removed. However, vegetation was left undisturbed between Stations 12 and 13. Another plankton collection was made at each of the three stations at 5:30 P.M. of the same day after the stream had sufficient time to clear. Results of these two collections are compared in Figures 14 and 15 and in Table 5.

TABLE 5. Organisms per liter in Maple River before and after vegetation removal between Stations 11 and 12. Vegetation was not removed between Stations 12 and 13. Compare numbers horizontally.

Vegetation	STATIONS		
	11	12	13
Before Removal	12,696	8,578	5,808
After Removal	10,496	10,270	7,493

The importance of vegetation as a factor in explaining the decrease of lake plankton as it flows down stream is clearly demonstrated by data in Table 5. Before vegetation was removed plankton leaving the lake underwent a 32 per cent decrease as it flowed from Station 11 to 12, and approximately the same decrease as it flowed from Station 12 to 13. This is rather representative of other collections during late summer in this section of the stream. After vegetation was removed, between Stations 11 and 12 but not between Stations 12 and 13, lake plankton flowing from Station 11 to 12 underwent practically no decrease, but decreased 27 per cent between Stations 12 and 13. The influence that this vegetation had on the various plankton groups is illustrated in Figures 14 and 15. Further analysis of data from this study showed that each predominant plankter was effected by the vegetation and all to approximately the same degree. Thus, when lake plankton decreases quantitatively on flowing through a vegetation bed it is not due to the removal of any one plankton group or individual plankter, but rather to the removal of some of each predominant form.

On November 4, 1933, two months after vegetation had been removed between Stations 11 and 12, a collection was taken (Table 6) to confirm the previous findings. At this time, lake plankton flowing from Station 11 to 12 underwent practically no decrease but decreased 20 per cent between Stations 12 and 13.

Non-Vegetation Zones

The most pronounced quantitative decrease of lake plankton as it flowed down stream almost invariably occurred in vegetated sections. However,

certain non-vegetated sections exhibited a small decrease throughout the summer and often it became rather conspicuous during autumn. That portion of Maple River between Stations 13 and 15 was studied for the purpose of determining what factors other than vegetation might aid in producing the observed plankton decrease. This part of the stream was characterized by shallow water free from vegetation except on the margins. On August 27, 1932, lake plankton flowing from Station 13 to 15 underwent a decrease of 87 per cent. On October 28, 1932, there occurred an 88 per cent decrease between the same stations. These collections were made at a time when this section of the stream was dammed in several places with large accumulations of leaves, fragments of dead vegetation and fallen branches from near-by trees. An examination of this material revealed the presence of large numbers of the predominant plankters occurring at Station 11. Diatoms were the most numerous but nearly every predominant plankter occurring at the outlet was represented in this material. Most of the leaves and branches were coated with a slimy sediment containing various epiphytic algal forms, and it was to this material that plankters seemed to adhere. Most of these were loosely attached and could easily be removed by moving the leaves back and forth in the water. Many plankters adhering to this material were living but remains of many others were observed. The collection of July 8, 1933, showed that lake plankton flowing from Station 13 to 15 underwent a decrease of only 38 per cent. This was taken at a time when this section of the stream contained little débris such as leaves and fallen branches. The decrease of plankton flowing from Station 13 to 15 while very pronounced is not as great per unit of distance as that occurring between Stations 11 and 13. The distance from Station 11 to 13 is only 20 meters and from Station 13 to 15 is 0.3 mile.

Lake plankton flowing down stream often underwent a small but consistent quantitative decrease in sections of the stream where there was an absence of vegetation and obstructing débris. A conspicuous feature of such sections was deposits of dark flocculent sediment on the margins. This deposition extended from the outer margin of the water to approximately 0.5 meter towards mid-channel but the outer limits showed the thickest deposition. Examination of this material revealed the presence of certain organisms normally occurring in the plankton, especially the following predominant diatoms: *Asterionella formosa*, *Fragilaria crotonensis*, and *Melosira varians*. Considerable numbers of *Ceratium hirundinella*, *Keratella cochlearis*, *Polyarthra trigla*, small numbers of nauplii and *Cyclops* sp. were present. Each of these plankters occurred regularly in the plankton at the outlet and together constituted a large percentage of the total net plankton.

In an attempt to account for these plankters in sediment, small pans were used to collect sediment at various positions across the stream. When the contents of these pans were centrifuged and examined microscopically they revealed the presence of numerous plankters. Material deposited in

the pans resembled in many respects the composition of sediment on the margins of the stream. Those pans nearest the margins contained the largest deposition of material while those in mid-channel contained the smallest. There was no attempt to make a quantitative comparison between organisms of the sediment and the plankton but qualitatively there was a striking resemblance. A feature common to sediments deposited on the stream margins and in the pans was that almost invariably the contained plankters had small particles of débris attached to them and in many instances several plankters were attached together by a mass of débris. Most plankters were dead but some living individuals were observed.

Sediment pans were distributed across the stream in the vegetation bed between Stations 11 and 13, and considerable material was deposited in them. This material was nearly identical in composition to that adhering to stems of plants and resembled that deposited on the margins of the stream in non-vegetated sections.

These observations on Maple River suggest that some plankters were removed from the water by sedimentation. It was not definitely demonstrated, however, that this process was an important factor in producing a conspicuous quantitative decrease of the plankton flowing down stream, but it is believed that it does function to a certain extent in quieter water and probably to a large extent in vegetation beds. Most data supporting this belief were derived from examination of numerous collections of sediment and bottom ooze from vegetation beds, pools, and margins of shallow water. The qualitative composition of this material was very similar in all instances and showed the presence of large numbers of organisms normally occurring in the plankton.

TABLE 6. Total plankton organisms per liter in Maple River, 1932, 1933.

Date	STATIONS						
	11	12	13	14	15	16	17
August 22.....	.....	.....	.....	.....	.....	307	93
August 24.....	8,172	.....	.....	.....	.....	84	52
August 26.....	.....	.....	.....	.....	.....	78	63
August 27.....	4,721	.....	2,169	931	284	101	75
October 27.....	24,051	16,417	7,138	1,311	.....	.....	.....
October 28.....	34,081	26,264	17,759	11,936	2,121	.....	.....
June 26.....	3,026	.....	2,486	1,881	.....	.....	.....
June 28.....	5,617	.....	4,114	.....	.....	.....	.....
July 8.....	4,721	.....	3,881	2,877	2,393	.....	.....
August 4.....	3,017	.....	1,945	1,722	.....	.....	412
August 17.....	5,331	4,328	3,077	.....	.....	.....	.....
August 28.....	12,696	8,578	5,808	.....	.....	.....	.....
August 28.....	10,496	10,270	7,493	.....	.....	.....	.....
November 4.....	42,300	40,500	32,300	16,700	12,100	.....	.....

PHYSICAL-CHEMICAL DATA

There was no attempt to make an extensive physical-chemical study of lakes and streams involved in this investigation. Analyses were made for the purpose of determining the general physical-chemical nature of lakes and to discover if there were significant chemical changes in water as it left them and flowed through those sections of streams exhibiting a pronounced plankton decrease.

A considerable amount of physical-chemical data from Douglas Lake has been published (Welch, 1928; Welch and Eggleton, 1932, 1935; Eggleton, 1931); therefore further analyses were unnecessary. Also, unpublished data secured by Professor Paul S. Welch for a chemical study of water flowing from Douglas Lake into Maple River made further chemical determinations unnecessary in the stream. These data showed that there was no significant chemical change in water as it flowed from Douglas Lake to a distance of 30 meters or more down Maple River. Determinations for hydrogen-ion concentration, dissolved oxygen, free carbon dioxide, carbonates, bicarbonates, and temperature were made at frequent intervals from a position in the lake approximately 10 meters from the outlet to a distance of 30 meters down Maple River. A similar study was made on the Bessey Creek-Lancaster Lake and Huron River situations with similar results.

DISCUSSION

Several authors have stated that plankton in certain portions of streams shows a quantitative decrease as it passes down stream. Richardson (1921) observed a 62 per cent decrease within a distance of 120 miles on the Illinois River. Galtsoff (1924) reported a quantitative decrease of approximately 45 per cent within a distance of 60 miles in a certain portion of the Mississippi River. Forbes (1928) stated that the quantity of plankton in the middle region of the Illinois River was nearly 15 times greater than the quantity in the region of the mouth. Also, Eddy (1932) found a quantitative difference in plankton of the upper and lower portions of the Sangamon River. Thus, it is evident from these and other reports, that a quantitative plankton decrease in streams had been observed previous to this investigation. However, none of the previous investigations had been on a stream without tributaries or pollution and deriving its water directly from a lake. Up to the present time, plankton investigations on streams have dealt with a plankton produced by the stream itself or the combined plankton of several streams and often one or more lakes. These situations contain many complex problems not only in respect to plankton composition but also physical and chemical conditions as well. Likewise, previous investigations have not been confined to an intensive study of a restricted portion of a stream but rather to a general survey of the entire river or some large portion of it. In most instances, previous investigators have

only suggested an explanation for the observed quantitative plankton decrease in streams, except in heavily polluted waters. In several instances, the quantitative decrease has been attributed to current but no one has conclusively shown this to be an important factor in itself. The present investigation has been an attempt to determine the nature of a plankton decrease in restricted sections of streams and of certain factors that are definitely related to it. This has been made possible by choosing situation deriving their water and included plankton from typical lakes, therefore eliminating many complicating factors in respect to plankton composition and physical-chemical conditions. It is realized that these data demonstrate the nature of a quantitative decrease of only typical lake plankton when entering a stream, but it is believed that the factors responsible for this decrease are also possible factors causing the decrease of other plankton in streams.

A study of the Huron River, Maple River and Bessey Creek showed that lake plankton entering a stream undergoes a quantitative decrease as it passes down stream. This decrease was demonstrated irrespective of season and was effective not only for total net plankton and various plankton groups but for the predominant individual plankters as well. The quantitative decrease in these streams is not uniform but small or large in different portions depending upon the presence or absence of certain environmental factors. It was shown that the quantitative decrease was definitely related to aquatic vegetation, to various kinds of débris and possibly to sedimentation. Other factors are associated with a quantitative plankton decrease but most of them are less conspicuous in their effects than those mentioned above.

Aquatic vegetation is believed to be one of the most important factors causing a quantitative plankton decrease in the streams investigated. A study of the Huron River for 18 consecutive months, demonstrated that the periods of greatest decrease occurred at times when the quantity of aquatic vegetation was the largest. Bessey Creek and Maple River, studied during two summers, showed that lake plankton underwent a small decrease as it flowed down stream in early summer when vegetation was scarce and a pronounced decrease in late summer when vegetation was abundant. Likewise, portions of these streams showing the greatest plankton decrease per unit of distance were those supporting a heavy growth of vegetation. The section of Bessey Creek between Stations 5 and 6, a distance of 15 meters, exhibited a decrease of 20 to 58 per cent when vegetation was most abundant. A vegetation bed of Maple River between Stations 11 and 13, a distance of 20 meters, showed a plankton decrease of 50 to 70 per cent at times of maximum vegetation production. The portions of these streams containing little or no vegetation throughout the summer likewise exhibited a consistently low plankton decrease. An intensive study of vegetation zones showing a very high percentage of decrease per unit of distance re-

vealed the fact that when vegetation was removed there no longer existed the pronounced plankton decrease.

It is rather evident that vegetation is related to the quantitative decrease but it is less evident how it functions. It can readily be seen how a dense mass of vegetation like the *Lyngbya* mat, between Stations 5 and 6 on Bessey Creek, could actually strain out plankters from water passing through it but how individual macrophytes remove plankton seems more difficult to understand. A large number of microscopical examinations of submerged stems and leaves of aquatic vegetation showed the presence of numerous epiphytic algae, filamentous algae, bacteria, stalked Protozoa, rotifers with organs of attachment, Turbellaria, insect larvae and large quantities of sediment in addition to many organisms normally occurring in the plankton. It was thus observed that this accumulation of material on macrophytes increased greatly from early to late summer. In early summer, individual plants supported such a small quantity of adhering material that it could be detected only by microscopical examination. By late summer, the accumulation of material was present in quantities that were easily visible and often so great that detached masses were seen floating down stream. Microscopical examination of plants in early summer showed the presence of only a few epiphytic algae, especially certain branched gelatinous stalked diatoms, filamentous algae, bacteria and a few adhering plankters. As the summer progressed, these non-plankton forms increased in number as well as the plankters. An attempt was made to determine if the rate of accumulation of material varied among different species of macrophytes but since it was nearly impossible to employ quantitative methods for this comparison definite conclusions are lacking. However, it appeared that *Najas flexilis* and *Chara* sp. accumulated material more rapidly than other plants. An explanation for this might lie in the fact that both plants have leaves with spine-like projections offering better conditions for straining out material from water. However, the composition of adhering material appeared to be nearly identical for all plants examined.

These observations suggest that aquatic plants are not effective plankton removers in early summer since they contain little adhering material. As the summer progresses, epiphytic forms which almost invariably attach themselves at right angles to their substratum, increase in number and probably strain out many other organisms from water. In many instances, these epiphytic forms had adhering to them filamentous algae, such as *Spirogyra* sp., *Mougeotia* sp., *Fragilaria crotonensis*, and *Melosira varians* which were so closely intermingled that a very effective straining device was produced. When such a combination was present on many plants composing a vegetation bed a large quantitative plankton decrease occurred within a very short distance, and many predominant plankters were found in this mass. If large numbers of plankters were being removed by this method, as it seemed certain they were, the question naturally arises as to

their ultimate fate. Plankters would not continue to accumulate on plants indefinitely without forming conspicuous masses. However, large accumulations were observed but when they reached a certain size portions became detached and either floated down stream, becoming attached to other objects, or sank immediately to the bottom. Without doubt many of these plankters were consumed by other inhabitants of the accumulated material.

Débris, such as decaying vegetation, accumulations of twigs and branches from trees, and especially dead leaves are believed to be definitely related to the quantitative plankton decrease which occurred in Maple River during the autumn of 1932. That portion of Maple River between Stations 13 and 15 contained little or no vegetation throughout the entire investigation and likewise it showed a small quantitative plankton decrease except in late summer and early autumn when this section was partially clogged with dead leaves and other débris. At this time, a quantitative plankton decrease of approximately 87 per cent occurred within a distance of 0.3 mile, showing a distinct contrast to the average summer decrease. Microscopical examination of leaves and débris forming the dams showed the presence of certain epiphytic algae, a slimy sediment and large numbers of predominant plankters. The plankters were not firmly attached but could be rather easily removed by shaking the leaves in water. Many plankters were alive but remains of dead individuals were also rather numerous. Among and beneath leaves composing the dams were large accumulations of sediment which, on examination, showed a composition almost identical with material adhering to leaves. These observations indicate that when plankters came in contact with exposed surfaces of leaves and other débris they either became attached and later dropped to the bottom or possibly were carried to the bottom immediately by settling material. This suggests that objects occurring in streams collect plankters on their exposed surfaces.

It has been shown that sedimentation was a possible factor in producing a quantitative plankton decrease in certain sections of Maple River. Sediment near the margins of the stream and that deposited in experimental collecting pans distributed across the stream contained many organisms normally occurring in plankton. A large deposition of sediment occurred on the margins of the stream where current was slowest but deposition was small in mid-channel where current was swiftest. It is believed that settling of plankton in Maple River is hastened by the large quantity of suspended particles of marl invariably present in the region of the lake outlet. Numerous observations have shown that these particles of marl and plankters often become associated and, under such conditions, it is reasonable to believe that these plankters settle rather quickly. Examination of sediment and bottom ooze in various portions of Maple River indicated that considerable quantities of plankton were settling out, especially in quiet waters near the margins, in pools, and to a great extent in vegetation beds. If sedimentation is an important factor in producing a quantitative

plankton decrease in Maple River, it is believed to vary considerably with rate of current and amount of suspended material in water. These results partially confirm those of Richardson (1921) who observed a rather large plankton decrease in a portion of the Illinois River. He stated, "These losses were greatest when the current was the slowest and settling consequently easiest." Also, he stated, "The river plankton is constantly settling to the bottom to an important degree as is shown by the composition of the bottom ooze and stomach contents of small invertebrates living in and on it."

Water level is probably related to a plankton decrease in streams. A rise in water level as shown by the Huron River almost invariably results in a smaller plankton decrease provided other conditions remained approximately the same. This was especially true during the spring and fall rains. Probably the significance of this lies in the proportion of water volume to exposed surfaces to which plankton might adhere. An increase in water volume results in the inundation of new areas above the old water line and deepens water of the main channel. In most instances, new objects are encountered by water over the inundated areas but probably very few of them have a surface favorable for plankton adherence, since they do not possess accumulations of sediment and epiphytic algae. Likewise, a deepening of water in the main channel reduces the proportion of water coming in contact with submerged objects. This suggests that a rise in water level results in a smaller proportion of plankton coming in contact with surfaces to which they might adhere, thus resulting in a smaller plankton decrease. A low water level was almost invariably accompanied by a large plankton decrease. This suggests that during periods of low water the proportion of water volume to exposed surfaces is smaller, thus more plankton come in contact with exposed surfaces.

Schroeder (1897), from an investigation on the Oder, concluded that the volume of plankton present in any stream is inversely proportional to rate of current. Kofoid (1903, 1908) states that the most important relation of current to plankton is its effect in determining the length of time in which plankton can breed. Allen (1920) came to the conclusion that water currents above a moderate speed are distinctly inimical to plankton development. Likewise, Van Oye (1926) and Galtsoff (1924) found current to be related to a scarcity of plankton in certain portions of streams. The current of the Huron River, Maple River and Bessey Creek is relatively slow and it was not shown to be definitely related to the quantitative plankton decrease except possibly in case of sedimentation which occurred more rapidly in quieter waters.

The quantitative plankton decrease occurring in streams investigated was not related to pollution, dilution, change in temperature or chemical change. Temperature did not vary more than 2°C. throughout the investigated courses of streams, and dilution by tributaries and pollution were absent in all situations. It was shown that there was no significant chemi-

cal change in water as it left lakes and flowed through those sections of streams exhibiting a pronounced plankton decrease.

It is evident that the quantitative plankton decrease exhibited by streams investigated is not caused by any one factor but by several (aquatic vegetation, débris, sedimentation, and others). One factor may be more important in one section of a stream than in another but the total plankton decrease occurring between the outlet of a lake and the most distant station on the stream may be due to the combined effect of several factors. The greatest plankton decrease per unit of distance occurred in those sections of streams possessing more than one effective factor. It seems that the greatest plankton decrease in streams is produced by collection of plankters on surfaces of objects with which they come in contact. Volume of water in proportion to amount of exposed surfaces in a stream is much less than in a lake; therefore, lake plankton entering a stream has a greater chance of coming in contact with exposed surfaces to which it might adhere.

SUMMARY

1. A qualitative-quantitative plankton study designed to determine the fate of typical lake plankton in streams was made on portions of the Huron River, Maple River and Bessey Creek, Michigan. Each portion studied derived its water from a typical lake and was without pollution or tributaries.

2. An eighteen months study of that portion of the Huron River formed by the outlets of Portage and Base Line Lakes demonstrates that lake plankton entering this portion of the river undergoes a quantitative decrease as it flows down stream, irrespective of season.

3. Summer studies on Maple River and Bessey Creek demonstrate that plankton entering from Douglas Lake and Lancaster Lake respectively undergoes a progressive, quantitative decrease as it passes down stream.

4. Quantitative plankton decrease in each of these streams is exhibited (a) by total net plankton; (b) by each large plankton group; and (c) by certain predominant individual plankters.

5. Plankton decrease was not uniform in all parts of each stream but varied with the presence or absence of certain environmental factors.

6. The greatest plankton decrease per unit of distance invariably occurred in heavily vegetated sections of each stream. A decrease of approximately 70 per cent occurred within a distance of 20 meters in a heavily vegetated portion of Maple River and a 60 per cent decrease within a distance of 15 meters in a vegetated zone in Bessey Creek. When the vegetation was removed from these sections, plankton decrease was no longer conspicuous.

7. Vegetation may act as a strainer in removing plankton from flowing water. Likewise, plankters may adhere to accumulated material on submerged stems and leaves of macrophytes.

8. Various kinds of submerged débris and objects may possess surfaces favorable for plankton accumulation.

9. Proportion of water volume to exposed surfaces of submerged objects probably influences the chance of plankters coming in contact with surfaces favorable for plankton accumulation.

10. Plankters settling to the bottom, either alone or in association with inanimate material, may aid in producing a plankton decrease.

11. Temperature, pollution, dilution from tributaries, current and a change in chemical conditions are not factors causing a plankton decrease in the streams investigated.

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